

A Regional Management Model of Fisheries in the Irish Sea

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Abstract: The Irish Sea is a moderately discrete area with mixed fisheries targeting a fairly small number of relatively well researched but depleted fish stocks, including *nephrops*, cod, whiting, haddock, plaice and sole. Vessels from Belgium, England, France, Northern Ireland, and the Republic of Ireland participate. The degree of dependence of the coastal communities on the fishery varies considerably but it is nevertheless a major contributor to output and employment in some localities. These characteristics make the Irish Sea an ideal subject for studying the possibility of managing the fishery as an entity.

The paper describes work, part-funded by the European Union FAR Programme, to develop a bio-economic model of the Irish Sea whitefish and *nephrops* fisheries. The objective of the model is to maximise the present value of the economic yield of the fishery subject to economic, biological, and institutional constraints under the assumption that the fishery is efficiently managed. The economic constraints include those of demand, production, costs, and social time preference rates. The biological constraints are those of the growth and recruitment characteristics of the stocks. The institutional constraints include the impact of limitations on changes in employment.

The model identifies the impact on national economies through a set of output and employment multipliers.

Keywords: Fishery Economics, Fishery Management, Bio-Economic Modelling

I Introduction

1. This paper describes work, part-funded by the European Union FAR Programme, to develop a bio-economic optimisation model of the Irish Sea whitefish and *nephrops* fisheries. It succeeds an earlier simulation model reported in Hillis *et al* (1995).
2. The Irish Sea is a moderately discrete area with mixed fisheries targeting a fairly small number of relatively well researched but depleted fish stocks, including *nephrops*, cod, whiting, haddock, plaice and sole. The fishery has exhibited the classic signs of open access - overcapacity and poor productivity for many years. Vessels from Belgium, England, France, Northern Ireland, and the Republic of Ireland, and to a lesser extent The Netherlands, Scotland, and the Isle of Man, participate. The degree of dependence of the coastal communities on the fishery varies considerably but it is nevertheless a major contributor to output and employment in some localities.
3. These characteristics make the Irish Sea an ideal subject for studying the possibility of managing the fishery as an entity. Regional management of fisheries at a level between the European Union, which currently has a Common Fisheries Policy applying throughout European Union waters though with exceptions for some measures, and its Member State has been under discussion for some time. This

model is intended to assist the discussion by examining one distinct regional fishery.

II The Structure of the Model

4. The objective of the model is to maximise the present value of the economic yield of the fishery subject to economic, biological, and institutional constraints under the assumption that the fishery is efficiently managed. The economic constraints include those of demand, production, costs, and social time preference rates. The biological constraints are those of the growth and recruitment characteristics of the stocks. The institutional constraints include the impact of limitations on changes in employment.
5. The model identifies the impact on national economies through a set of output and employment multipliers.
6. For the purposes of this model the economic yield to be maximised is defined as the aggregate profit of the fleets. This provides a target variable which is the discounted sum to infinity of the profits of each fleet.
7. To overcome the mathematical obstacle of optimising to infinity, the model solves for a twenty year period from 2000 to 2020 which is divided into two, a control period and an equilibrium adjustment period, and then adds a term to infinity covering the equilibrium period. A range of scenarios with

varying discount rates and varying institutional constraints was tested.

8. The model is set out in an *Excel* spreadsheet and includes sections for economic, biological, and institutional constraints, and a section for calculating the multiplier effects on the economies of the participating countries. The fleets of four countries are included; Belgium, France, the Republic of Ireland, and the United Kingdom. The UK fleets are sub-divided between England and Wales, and Northern Ireland. The remaining fleets are omitted either because their participation in the fishery in recent years has been as a substitute for other grounds or because they concentrate on the pelagic fishery which is not included in the model.
9. The control variable is the number of kilowatt days fishing by each fleet, except in the case of the Belgian fleet when the number of days fishing was used owing to the unavailability of data. The proportions of capital and labour used are assumed fixed, an undesirable assumption given that the fishery may have current proportions determined by near-open access conditions, but the data needed to estimate fleet production functions proved inadequate to allow the alternative assumption.

III The Economic Constraints

Prices and Demand

10. The Irish Sea is a relatively small contributor to the domestic landings of the four nations included in the model. In such circumstances the fishery may be expected to be a price-taker from the larger markets. This was assumed to be the case for all species and in each country.
11. The relationship between landings and price was investigated econometrically for *nephrops* in France, Ireland and the United Kingdom as it had been expected that landings from the Irish Sea would be a significant influence on prices in the domestic markets. However, no significant relationship could be found. While this was unexpected it is not surprising as in recent years new grounds for *nephrops* have been developed and the Irish Sea is no longer the dominant source, though it has not lost any of its previous importance.

Production

12. Fleet output for each species is a function of the stock biomass and production inputs. The inputs have been reduced following econometric investigation to a

single non-stock input, kilowatt days fishing per fleet, except for the Belgian fleet where days fishing were used. The coefficients estimated were used throughout.

13. However, no data is available for the Irish fleet fishing in the Irish Sea, and insufficient data exists for haddock and Belgian landings of *nephrops*. For all these, intuitive estimates of the coefficient values were made. In addition, the stock coefficient estimated for Northern Irish *nephrops* output, despite being significant appeared to have an unrealistic value and was tuned.
14. While it would have been preferable to estimate production functions for each fishing method used, there was insufficient data available to undertake this exercise. The Belgian and French fleets use a single fishing method, beam trawling and otter trawling. Thus there has been no loss of information for their activity, but the English, Irish and Northern Irish Fleets readily switch between whitefish trawling and *nephrops* trawling. In essence these are the same fishing method but with different minimum legal mesh sizes, broadly 100mm for purely whitefish trawling and 70mm (with a square mesh panel) for purely *nephrops* trawling.
15. All the constant terms were adjusted to enable estimated production levels in 1999 to meet their officially reported level in 1998, the last year for which adequate data were available.
16. Two exceptions to this emerged in the process of developing the model. The haddock TAC has not reflected the rapid growth in the stock in recent years and it is suspected that officially declared landings may understate the true level. Secondly, Fixed Quota Allocations were introduced in the United Kingdom fisheries from January 1999. It is thought that the 1998 *nephrops* landings figures may reflect over-reporting of landings intended to protect British vessels' track record and that a similar practice occurred among Irish vessels.

Costs

17. Costs are given as a linear function of a level of fixed costs and a unit cost of output. It was assumed that in 1999 the fleets made no (economic) profit and therefore that costs exactly equalled revenue. Then from observation of reported costs and earnings of the United Kingdom fleet (SFIA 1999) it was assumed that fixed cost comprised 25% of total costs.
18. Given the level of input, the unit cost of inputs was then calculated and assumed constant throughout the

optimisation period. In the absence of data on inputs for the Irish fleet, an estimate was made of the number of kilowatt days fishing that might have been needed to catch the reported levels of landing was made.

Social Time Preference Rate

19. While there are several estimates of the appropriate level of social time preference rate to use (eg Jarden & Co 1988 for New Zealand, and Hillis *et al* 1995 for the Irish Sea) these appear high and may reflect the absence at the time of management regimes which encourage economic efficiency. Hence, it was decided instead to run the model under a range of rates - 0%, 5%, 10%, 20%, 30% and 50%.

IV The Biological Constraints

Stock Biomasses

20. The 1999 stock numbers by species by age cohort are used as the starting point for the model (ICES 1999a).
21. In each successive time period the number of fish in each cohort is reduced by natural mortality and the number of fish landed and discarded is subtracted. Thus the progress of a cohort may be followed along a diagonal as the cohort ages. The numbers of fish are multiplied by the weights at age and summed to give a stock biomass for each year.
22. Spawning stocks are estimated by a similar process but the biomass in each cohort is multiplied by the proportion of fish sexually mature at each age.
23. A shortcoming of this procedure is that the growth rates of the stock are not conditioned by the proximity of the biomass of all species to the environmental carrying capacity (ECC) of the Irish Sea. To overcome this, as retardation of the growth rate is more complex and difficult to calculate than an increase in the natural mortality of the stocks, the natural mortality of the stocks is increased as the stocks' biomass approaches the ECC such that stock growth will be zero at the ECC.

Recruitment

24. Fish of age-group zero have been excluded from the model as their contribution to the fishery is minimal. Recruitment of fish to the one year old cohort is assumed to take the level of the arithmetic mean of the ten years to 1999.

Natural Mortality

25. Natural mortality takes the values used by ICES (1999a). However, fisheries scientists apply these mid-year after some fishing has taken place. This is not possible as the model treats each year as a single moment and the arbitrary decision was taken to apply natural mortality to the stock level before fishing takes place.
26. While this impacts upon the stock levels at the end of each year, it may also have altered the relationship between the stock biomass and output modelled econometrically. However, the error introduced is almost certainly much less than that in the natural mortality values used which were determined by scientific practice. More detailed knowledge of natural mortality levels in the North Sea, where similar intuitively-determined level had been used, suggests that the natural mortality levels for the younger cohorts (and therefore the stock numbers present) have been considerably higher - sometimes by a factor of ten in the 0-group (ICES 1999b)

Environmental Carrying Capacity

27. The size of the total biomass of living creatures or of the particular stocks included in the model that could be supported by the Irish Sea is not known.
28. However, it follows that there must be some limit, and given that the Irish Sea has in part been the recipient of overspill from neighbouring fisheries, it is not thought that there is a great deal of scope for the stocks to grow from their current levels.
29. To establish a limit against which to apply the stock biomasses, the sum of current TACs for the six stocks was taken as a proportion of the sum of the best TACs that each had experienced since 1983 when the TAC regime was applied, with some adjustment for the impact of the Hague Preference Agreement.
30. The current aggregate biomass of the six stocks was divided by this quotient to give an estimate of the maximum that the aggregate stocks could realistically be expected to reach. It amounted to approximately twice the current level. This figure was used for the ECC.

V The Institutional Constraints

31. The model has been run under four institutional scenarios. The first is unrestrained, so that the model is free to determine the optimal without hindrance.

This assumes that TACs are set at the optimal level of landings.

32. The second scenario assumes that the level of non-stock inputs will be changed to a new and permanent level to infinity.
33. The third scenario assumes that the level of non-stock inputs will be permitted to change by no more than 10% from the level in the previous year. Implicit in this is that changes in the level of employment in fishing are congruently constrained, because of the assumption of fixed input factors.
34. The fourth scenario assumes that any losses in the initial years which might arise from a reduction in fleet activity will be underwritten by the state but that no compensatory clawing back of the subsidies will occur.

VI The Output and Employment Multipliers

35. Supply-driven multipliers were calculated for output and employment for each country and were applied to the changes in output and employment to assess the total impact of the changes in the fishery. The multipliers were calculated using input-output analysis (Leontief 1952). These suffer the shortcoming of linearity and assume constant factor inputs. Nevertheless, given that the results do not generally move far from the current position, they serve as a reasonable approximation.

VIII Results

36. Two scenarios are reported here each with a 10% social time preference rate applied; first, showing the progress of the fishery if levels of activity were to remain at their reported 1999 levels, and secondly if optimal levels of activity were applied subject to the constraint that a change was permitted of no more than 10% on the levels calculated as optimal for the previous year.
37. The model has also been run under three other scenarios; i) unconstrained optimisation, ii) with new but constant levels of fishing activity to infinity, and, iii) with an arbitrary percentage cut for 5 years with free optimisation thereafter.
38. While the unconstrained optimisation suggests considerable profitability may be obtainable from regional management (since activity levels are chosen to obtain the greatest sum of profits among the participants) the model displays some tendency to

oscillate, probably caused by the low recruitment rates in 2000, particularly for cod. In subsequent years mean recruitment is used. In addition, the optimal activity levels calculated appear unrealistic and prone to interplay with the solver tolerances especially for the smaller fleets.

39. The first scenario, constant activity at 1999 levels, suggests that fishing could continue into the future with little change. The fishery is currently rather run-down and displays the characteristics of over-capacity, but is replenished each year in the model by the assumption of constant mean recruitment (limited only by the environmental carrying capacity) and some supplementation by neighbouring fish stocks.
40. Although the whitefish stocks may be susceptible to being fished out as economic entities, this is not so readily the case with the *nephrops* because of the habit of the female of burying herself for several months of the year.
41. The progress of discounted profits shown in Figure 1 indicates that the Northern Irish fleet would gain from continuing the current levels of activity while there would be some losses for the other fleets. This reflects the importance of the *nephrops* fishery to the Northern Irish fleet and the improved biomasses suggested for *nephrops* and shown in Figure 2.
42. The situation depicted in Figures 1 and 2 is unlikely to come about for a number of reasons, but is given as a base option. The United Kingdom introduced a new quota allocation system, Fixed Quota Allocations (FQAs) in January 1999. These have become tradeable and so both English and Northern Irish fleets may be seen as in a transitional period as the last vestiges of open-access are shed. The fishery has not been open-access to any fleet for some time, as entry by licence is needed and quotas apply, but the new United Kingdom system is a *de facto* ITQ regime. A more general question is whether recruitment is likely to be distributed about the mean since water temperature changes round the British Isles are thought by ICES scientists to be reducing recruitment level.
43. The alternative scenario of optimisation with a constrained change in activity levels from year to year suggests that a slow reduction in activity totalling 35% over a period of ten years is needed with little variation between fleets. This is somewhat less than the immediate cut of 40% advocated by fisheries scientists (Lassen 1996) and is shown in Figure 3.

- 44. The sum of discounted profits available is, however, much improved as shown in Figure 4 and amounts to €48.5m
- 45. The progress of the stocks is shown in Figure 5. *Nephrops* levels increase but there is a slight fall in the quantity of cod available and a more marked fall in the plaice stock.

- 46. In both scenarios shown, employment levels follow the levels of activity because of the assumption of fixed proportions of inputs imposed by the absence of adequate data on crew sizes in the fleet

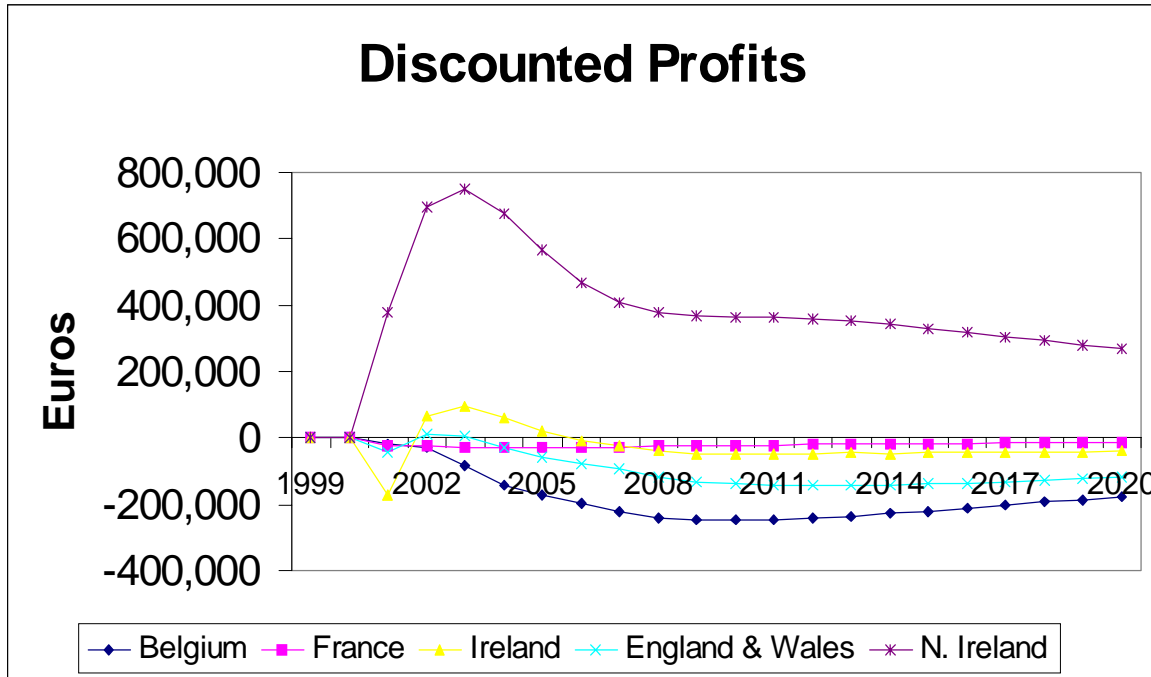


Figure 1

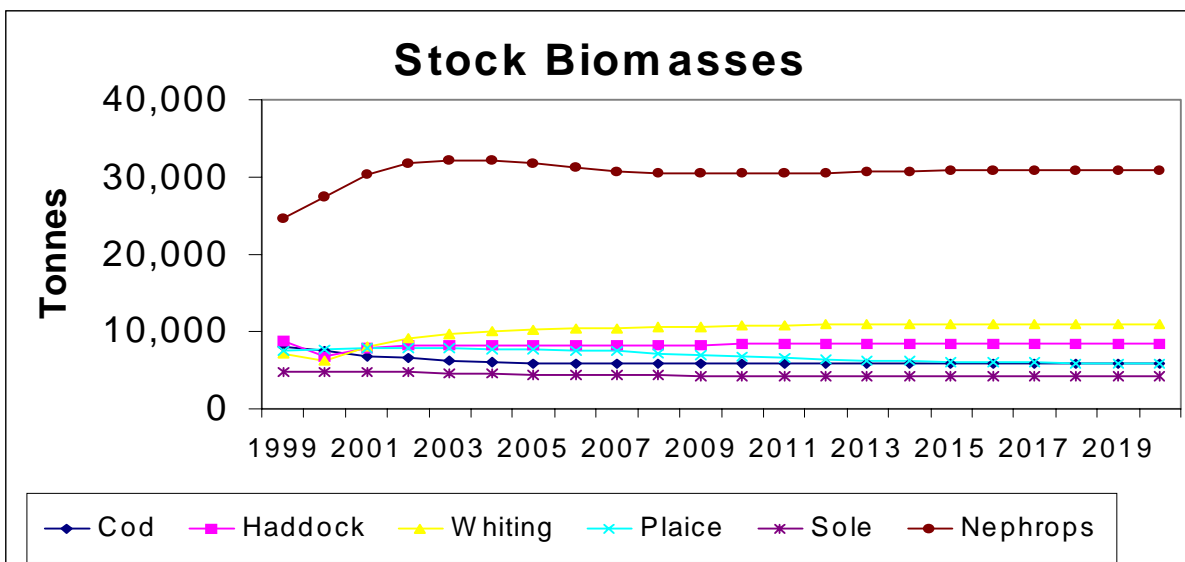


Figure 2

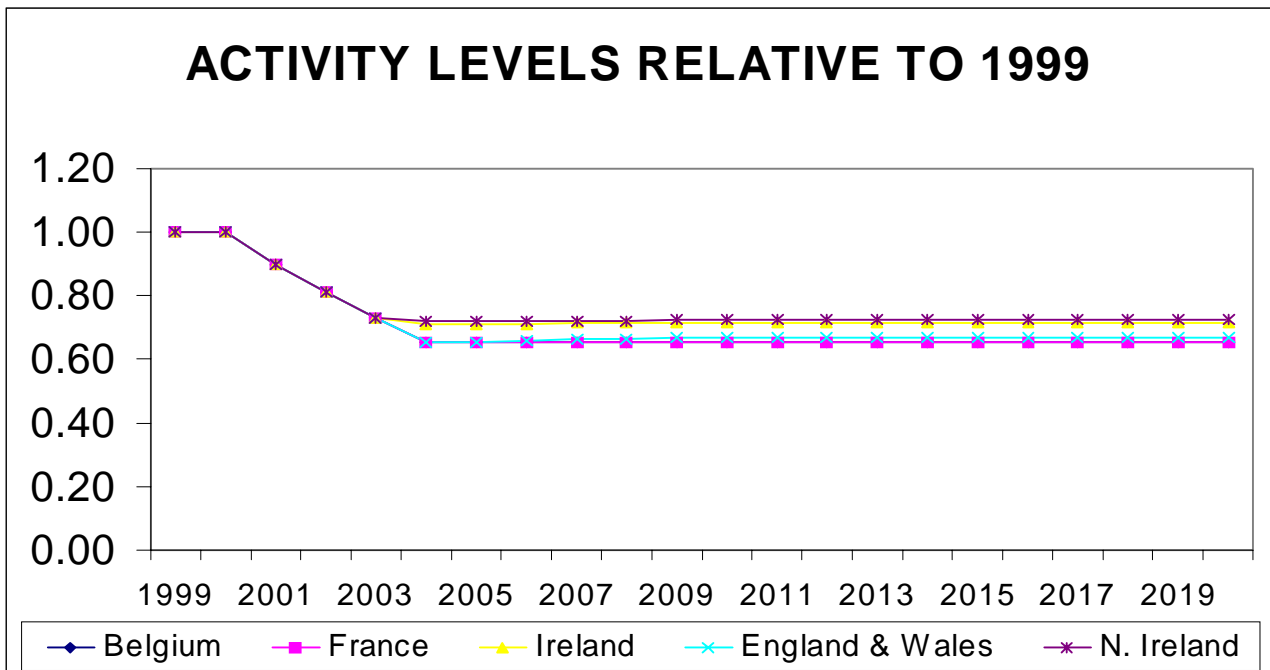


Figure 3

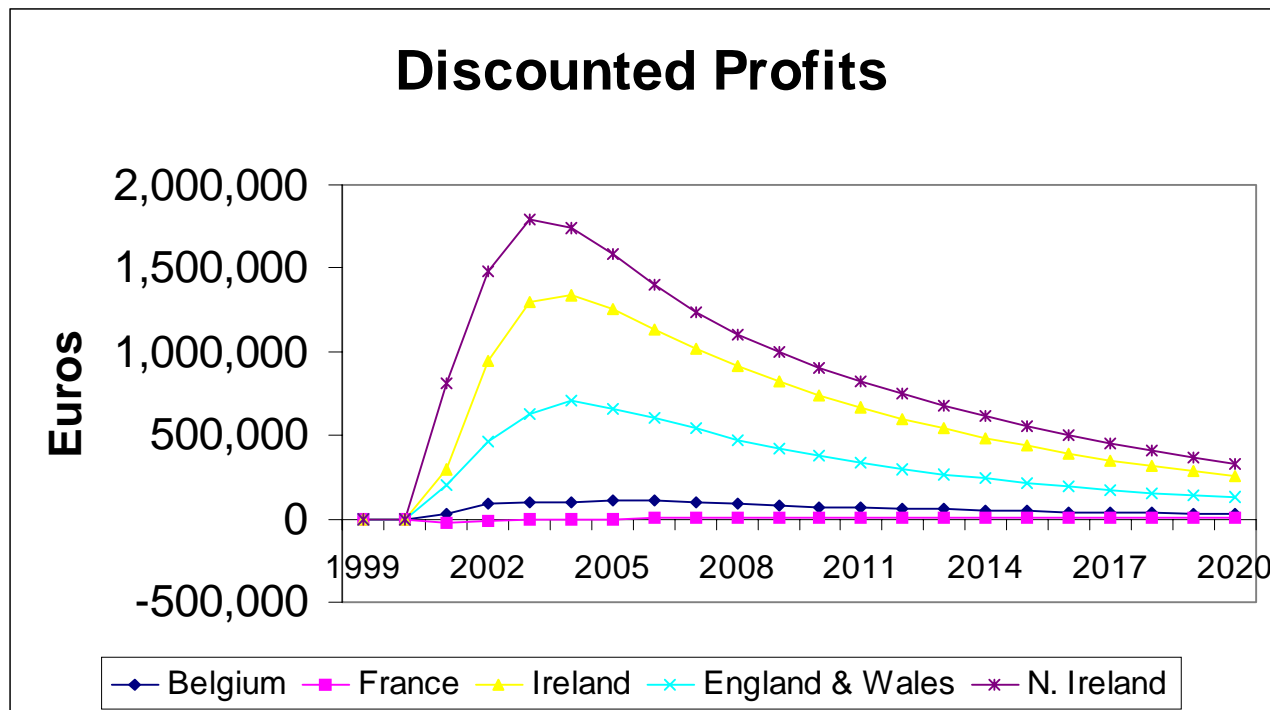


Figure 4

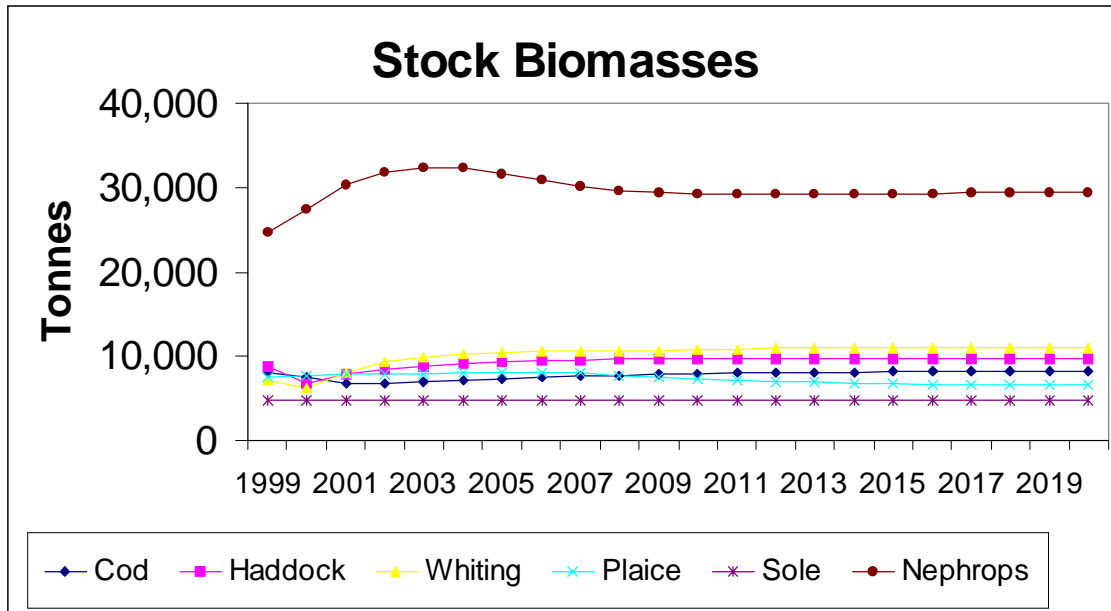


Figure 5

IX Conclusions and Inferences

47. The primary conclusion is that while the fishery may continue for many years to come, there are substantial gains to society to be obtained by using an economically efficient management regime and further gains to be made by regional management of the Irish Sea fishery as an entity.
48. While the model identifies profits to be made, it is of course the case that these cannot be permitted to accrue otherwise they would attract investment which would quickly destroy them. In fact, the sum of profits calculated by the model represents the discounted present capitalised value of licences and quota, or the windfall that has befallen present-day holders of licences and quota entitlements. With this value the fishery earns a normal return to capital.
49. The model attempts to examine the socio-economic implications of efficient management on a regional scale by using output and employment multipliers to show the impact on the national economies. The profits obtainable are offset by lost employment as the optimal level of activity is, for all fleets, below the current level. Leaving aside the problems introduced by the assumption of fix proportions of input, the profits only truly accrue to society if there is full employment of labour, so that the resources shed are immediately taken up in another activity. This is not a realistic assumption

throughout the whole of the fishery. Most places offer little alternative to fishing. Thus the socio-economic aspects of the model remain to be explored fully.

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Appendix

THE BIOECONOMIC MODEL

The aim has been to describe a detailed general model of a multispecies fishery. Allowance has been made for the stock of each species to have a set of age cohorts.

The species included in the model are cod, haddock, whiting, plaice, sole and *nephrops*. These species have been the principal species by value landed from the Irish Sea fishery prosecuted by trawling. Among them haddock has only recently become important following a marked increase in the stock in the Irish Sea.

No attempt has been made to separate the fishing methods owing to a paucity of data but this is not thought to have seriously weakened the model. Fishing method is most important when it reflects differences in vessels and hence productivity and costs. However, the Belgian and French vessels fishing in the Irish Sea each use only a single method and the Irish and British fleets use the same vessels but switch between target species from whitefish to *nephrops*.

The distinguishing feature of the model presented here is that it includes a section where the on-shore effects on output and employment are calculated to portray the socio-economic impact of changes in the fishery on localities which are highly dependent on it. The most significant assumption underlying the model is that the fishery is efficiently managed as a single entity with all participants facing the same institutions, so that no fleet has an advantage over the others. To avoid undue complexity some of the subscripts for countries have been omitted.

The Objective Function of the Model

The objective of the model is to maximise the net discounted present value of profits to infinity from the fishery

$$Z_0 = \sum_0^{\infty} (\bar{p} Q_t - C_t) / \partial_t$$

Where \bar{p} is the exogenously given price level, Q is the level of landings per species, C is the cost of fishing, and ∂ is the discount rate.

The Economic Constraints

The Production Functions

The production function is of the form

$$Q_f = \alpha_0 S_f^{\alpha_1} I^{\alpha_2}$$

Where S is the stock biomass and I is the level of inputs.

The Cost Functions

The form of the cost function used in the model is

$$C = \gamma_0 + \gamma_{31} I$$

C is total cost of inputs.

The Biological Constraints

The Stock Identities

The stock size is given by the standard Beverton-Holt function for age cohorts with a correction factor applied representing the weight-at-age of a fish divided by the weight at its previous age

$$S_{f,A} = (S_{f,A-1} - H_{f,A-1}) \frac{WT_{f,A}}{WT_{f,A-1}} e^{-M_{f,A}}$$

where A represents the age cohort, H is the harvest in the previous time period and WT is the weight of an individual (Beverton and Holt 1957). The stock biomass is the sum of these.

$$S_f = \sum_0^a S_{f,A}$$

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ENDNOTES

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